

# It's in Their Nature

## Solute-Solvent Interactions

### Introduction

*"Oil and water do not mix."* How many times have you heard this old saying? As metaphor, it is often used to explain why relationships between opposites are difficult or even impossible. Let's trace this metaphor back to its source—the nature of oil and water, solutes and solvents, and why some substances do not dissolve in or mix well with others.

### Concepts

- Solute and solvent
- Polar vs. nonpolar
- Intermolecular forces
- Miscibility of liquids

### Background

A solution is a homogeneous mixture of two or more substances. The word homogeneous means that a solution must be uniform throughout its contents. The composition or concentration of a solution can be changed by changing the amount of the solute (the minor component) dissolved in a given amount of the solvent (the major component). Although many common solutions contain solids dissolved in liquids, both the solute and the solvent may exist in any phase (solid, liquid or gas). Solubility is a characteristic property of a pure substance and can be used to help identify different substances. Thus, a chemistry handbook will usually report the solubility of a substance in different solvents along with other physical properties such as melting point, density, etc.

When a solute dissolves in a solvent, the attractive forces acting between solute particles and those between solvent molecules must be broken and replaced by new attractive forces between the solute and solvent. The nature and strength of the attractive forces among solute and solvent particles influences whether a solute will dissolve in a solvent. Many ionic compounds, for example, dissolve readily in water. Water is a highly polar molecule, with a great degree of charge separation between the oxygen and hydrogen atoms in its O—H bonds. Upon dissolving in water, an ionic compound breaks apart into its component ions, which are attracted to the partially charged ends of the highly polar water molecules.

Molecular compounds consist of molecules—groups of atoms held together by covalent bonds—rather than ions. The physical properties of a molecular compound, including its solubility, depend on the polarity of the molecules. Molecules are classified as polar or nonpolar based on the nature of the electron sharing among the atoms in a molecule. Polar molecules tend to exert stronger attractive forces than nonpolar molecules. The polarity of a compound determines the types of intermolecular attractive forces between molecules and is an important factor influencing the solubility of solutes and solvents.

### Experiment Overview

The purpose of this experiment is to investigate the solubility of ionic, polar, and nonpolar compounds in a variety of solvents. The solubility patterns of different solutes and solvents will be used to classify compounds and to understand the nature of the interactions between solute and solvent particles.

### Pre-Lab Questions

1. Is the iodine molecule polar or nonpolar? Explain.
2. The formula of hexane is  $\text{CH}_3\text{—CH}_2\text{—CH}_2\text{—CH}_2\text{—CH}_2\text{—CH}_3$ . Based on its structural formula, is hexane a polar or nonpolar compound? Explain.
3. Draw the structure of a water molecule and explain why it is polar. Show by means of a diagram the types of attractive forces acting between water molecules and also between water molecules and dissolved ions such as  $\text{Na}^+$  and  $\text{Cl}^-$  ions.

### Materials

Benzoic acid, $\text{C}_6\text{H}_5\text{COOH}$ , 0.5 g	Beral-type pipets, 4
Cholesterol, $\text{C}_{27}\text{H}_{46}\text{O}$ , 0.5 g	Distilled or deionized water
Dextrose, $\text{C}_6\text{H}_{12}\text{O}_6$ , 0.5 g	Graduated cylinder, 10-mL
Ethyl alcohol, $\text{C}_2\text{H}_5\text{OH}$ , 15 mL	Paper towels
Hexane, $\text{C}_6\text{H}_{14}$ , 17 mL	Spatula
Iodine, $\text{I}_2$ , 0.5 g	Test tubes, 6
Potassium nitrate, $\text{KNO}_3$ , 0.5 g	Test tube rack
Toluene, $\text{C}_6\text{H}_5\text{CH}_3$ , 6 mL	Wash bottle

### Safety Precautions

*Ethyl alcohol, hexane, and toluene are flammable organic solvents and dangerous fire risks. Keep away from flames and other sources of ignition. Addition of denaturant makes ethyl alcohol poisonous. Toluene is moderately toxic by ingestion, inhalation, and skin absorption. Work with these solvents in a well-ventilated lab only and avoid breathing their vapors. Iodine is toxic by ingestion or inhalation. It is a skin and eye irritant and will stain skin and clothing. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles and chemical-resistant gloves and apron. Wash hands thoroughly with soap and water before leaving the lab.*

## Procedure

### Part A. Solubility of Iodine

1. Obtain four clean test tubes and place them in a test tube rack. Using Table 1 as a guide, add about 2 mL of the appropriate solvent to each test tube. *Note:* Use a graduated cylinder to measure and add 2 mL of water to test tube #1, then compare liquid levels to add about the same volume of other solvents to test tubes #2-4.

Table 1.

Test tube	1	2	3	4
Solvent	Water	Ethyl alcohol	Hexane	Toluene

2. Using a spatula, add one crystal of iodine to each test tube.
3. Gently swirl or tap each test tube and observe the mixtures. Beneath the name of each solvent in the data table, record whether iodine is soluble or insoluble in the solvent and the color of the solution (if appropriate).
4. Dispose of the contents of the test tubes in the "Iodine Waste" container provided by your instructor.
5. Rinse each test tube twice with water and dry them with a paper towel for use in Part B.

### Part B. Miscibility of Solvents

6. Place six clean test tubes in a test tube rack. Add about 2 mL (40 drops) of water to test tubes #1, 2, and 3.
7. Add about 2 mL of hexane to test tubes #4 and 5.
8. Add about 2 mL of toluene to test tube #6.
9. Using Table 2 as a guide, add 20 drops (about 1 mL) of a second solvent to each test tube.

Table 2.

Test tube	1	2	3	4	5	6
First solvent (2 mL)	Water	Water	Water	Hexane	Hexane	Toluene
Second solvent (1 mL)	Ethyl alcohol	Hexane	Toluene	Ethyl alcohol	Toluene	Ethyl alcohol

10. Gently swirl or tap each test tube to mix the contents.
11. Next to the name of each solvent pair in the data table, record whether the two liquids form one or two layers upon standing. If the mixtures separate into two layers, report which solvent is the upper layer.

12. Dispose of the contents of the test tubes in the "Organic Waste" container provided by your instructor. Rinse each test tube twice with water and dry them with a paper towel before using them in Part C.

**Part C. Solutes and Solvents**

13. Obtain six clean test tubes and label them #1–6.
14. Add about 2 mL (40 drops) of the appropriate solvent to each test tube, as shown in Table 3.

**Table 3.**

Test tube	1	2	3	4	5	6
Solvent	Water	Ethyl alcohol	Hexane	Water	Ethyl alcohol	Hexane

15. Using a clean spatula, add a small amount (about the size of a grain of rice) of dextrose to test tubes #1, 2, and 3.
16. Wipe the spatula with a clean paper towel, then add a small amount (about the size of a grain of rice) of potassium nitrate to test tubes #4, 5, and 6.
17. Gently swirl or tap each test tube to mix the contents.
18. In the data table, record whether each substance is soluble or insoluble in each solvent.
19. Dispose of the test tube contents as directed by your instructor.
20. Rinse each test tube once with about 1 mL of the appropriate solvent, and then add about 2 mL of fresh solvent to each tube. Use the same solvent arrangement shown in Table 3.
21. Using a clean spatula, add a small amount (about the size of a grain of rice) of cholesterol to test tubes #1, 2, and 3.
22. Wipe the spatula with a clean paper towel, then add a small amount (about the size of a grain of rice) of benzoic acid to test tubes #4, 5, and 6.
23. Gently swirl or tap each test tube to mix the contents.
24. In the data table, record whether each substance is soluble or insoluble in each solvent.
25. Dispose of the test tube contents as directed by your instructor. Wash and rinse the test tubes.

Name: \_\_\_\_\_

Class/Lab Period: \_\_\_\_\_

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### Data Tables

#### Part A. Solubility of Iodine

Solvent (Test Tube)			
Water (1)	Ethyl alcohol (2)	Hexane (3)	Toluene (4)

#### Part B. Miscibility of Solvents

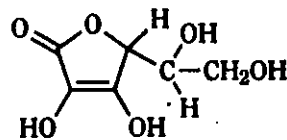
Solvent Pair (Test Tube)		Solvent Pair (Test Tube)	
Water Ethyl alcohol (1)		Hexane Ethyl alcohol (4)	
Water Hexane (2)		Hexane Toluene (5)	
Water Toluene (3)		Toluene Ethyl alcohol (6)	

#### Part C. Solutes and Solvents

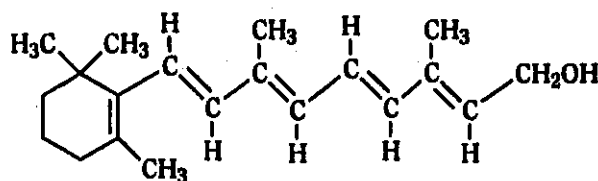
	Water	Ethyl alcohol	Hexane
Dextrose			
Potassium nitrate			
Cholesterol			
Benzoic acid			

**Post-Lab Questions** (Use a separate sheet of paper to answer the following questions.)

1. In which solvents is iodine soluble? In which solvents is iodine insoluble?
2. Define the term miscibility, then circle the correct choice in each statement to summarize the miscibility of the solvent pairs tested in Part B:  
Water and ethyl alcohol are (*miscible/immiscible*).  
Water and hexane are (*miscible/immiscible*).  
Water and toluene are (*miscible/immiscible*).  
Hexane and ethyl alcohol are (*miscible/immiscible*).  
Hexane and toluene are (*miscible/immiscible*).  
Toluene and ethyl alcohol are (*miscible/immiscible*).
3. Rank the four solvents tested in Parts A and B in order from most polar to least polar (nonpolar). Which two solvents are most alike in their polarity? Explain your reasoning.
4. Write a general statement describing the solubility of nonpolar solutes in different solvents and suggest a reason for this pattern.
5. Potassium nitrate (Part C) is an ionic compound. Write a general statement describing the solubility of ionic compounds in different solvents.
6. Dextrose, cholesterol, and benzoic acid are molecular (organic) compounds. Based on their solubility patterns in Part C, arrange these three solutes in order from most polar to least polar. Explain your reasoning.
7. Based on its solubility, would you expect cholesterol to be soluble in the bloodstream? Where does cholesterol tend to accumulate in the body? Why?
8. Vitamins are classified as either water-soluble or fat-soluble. The structures of Vitamin C (water-soluble) and Vitamin A (fat-soluble) are shown below. Identify the features of these molecules that give them their characteristic solubility.



Vitamin C



Vitamin A

9. The simple rule "*Like dissolves like*" is often used to describe the solubility of a substance in different solvents. Write a short paragraph discussing your evidence for this rule. Include in your discussion where you think this rule works best and where it seems to be less reliable. Give specific examples to back up your statements.
10. (Optional) A drop of motor oil spilled on wet pavement will quickly spread out into a thin film. A drop of water spilled on a greasy plate, however, will bead up into a little sphere. Use these observations, and the nature of solute-solvent interactions, to explain why oil and water do not mix.